CENTRIFUGES REPLACEMENT STUDY PROPOSAL

By

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Executive Summary

Primarily this paper was written to provide a general understanding of centrifuging phenomenon, invention and brief historical developments of centrifuges and their application in industrial world. Part of this paper is specifically dedicated to a detail evaluation study of conventional vertical 'basket' type centrifuges installed at 'ABC' manufacturing facility and a proposal of their replacement with modern design 'peeler' centrifuges.

Advantages and disadvantages of basket (vertical) and peeler (horizontal) type centrifuges are discussed and evaluated. Chapters in the final part of the paper present a converged study of historic maintenance and operational costs associated to the basket type centrifuges installed at 'ABC' manufacturing facility. Design comparison of two types of centrifuges is made and study of alternative and replacement theory is used to make the final conclusion.

Overall, the paper covers the different perspectives of centrifuge applications, design philosophy, maintenance and operational costs, and replacement/investment study.

The analysis of the available data in the paper presents a final recommendation of replacing the basket type centrifuges with peeler design centrifuges at 'ABC' manufacturing facility. Finally select appendices are included providing additional information to support the contents of the paper.

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General Centrifuges Information

Introduction to Centrifuges

Centrifuge is a device which uses **centrifugal force** to separate two or more substances of different density, e.g., two liquids or a liquid and a solid. The centrifuge consists of a fixed base or frame and a rotating part in which the mixture is placed and then spun at high speed.[1] In some other words centrifuge is an apparatus consisting essentially of a compartment spun about a central axis to separate contained materials of different specific gravities, or to separate colloidal particles suspended in a liquid.[2] In simplest term centrifuge is an apparatus that uses centrifugal force to separate particles from a suspension.

Centrifugal Force, Definition and Calculation

The apparent force, equal and opposite to the centripetal force, drawing a rotating body away from the center of rotation, caused by the inertia of the body. Centrifugal force is a force that tends to move objects away from the center in a system undergoing circular motion. Centrifugal force keeps the water in a whirling bucket from spilling or throws a rider in a car against the door when the car goes around a sharp curve. Centrifugal force is actually a form of inertia.[6] Following examples elaborating this force with a practical meaning:

Centrifugal force definition is used to express that if an object is being swung around on a string the object seems to be pulling on the string. In actual fact the person holding the string is doing the pulling. When an object is at speed, then if no force is exerted the object will continue in a straight line. To make the object deviate from that straight line a force must be exerted. When a stone is being swung around on the end of a rope the tension in the rope is transmitting the force

directed to the center that is being exerted by the person swinging the rope. On the other end of the rope the stone is attached and since the stone itself is not attached to anything it cannot resist the force and the direction of motion is bent; towards the center.[6]

The force directed away from the center that corresponds to an amount of mass m at a distance r from the center is given by:

$$\mathbf{F} = \frac{mv^2}{r}\frac{\mathbf{r}}{r} = m\omega^2\mathbf{r}$$

(Where m is mass, v is velocity, r is radius of the circle, ω = v / r is the angular velocity, and the **r** is the vector pointing from the center to the tip).

Invention of Centrifuge

Although the centrifugal force and its application has been used by human beings since ages in one or other form. It was not until early 1700s when an English military engineer Benjamin Robins (1707-1751) invented a whirling arm apparatus to determine drag. The first successful centrifuge was built in 1883 by Carl G. P. de Laval, a Swedish engineer, whose design was used chiefly for cream separators. The ultracentrifuge, devised in 1925 by the Swedish chemist Theodor Svedberg, found wide application in scientific research. Using an optical system with it to observe sedimentation rates, Svedberg determined accurately the molecular weights of substances including proteins and viruses. Svedberg won the 1926 Nobel Prize in Chemistry for his invention.

Types and Uses of Centrifuge

There are various types and designs of centrifuges, operating on the same basic principle, used in variety of applications.

1. Simple centrifuges are used in biology and biochemistry for isolating and separating bio-compounds on the basis of molecular weight. These will tend to rotate at a slower rate than an ultracentrifuge, and have larger rotors, and be optimized for holding large quantities of material at intermediate acceleration.
2. Washing machines use a centrifuge to partially remove the water from wet clothes.
3. One type is used for the separation of the solid and the liquid parts of blood. Test tubes containing blood specimens are set in the rotating part in holders so arranged that when the rotary motion begins the test tubes swing into a slanted or a horizontal position with the open ends toward the axis of rotation; the heavier, solid part of the blood is thrown outward into the bottom of the tube and the lighter liquid part comes to the top. This process is used to separate white cells and/or platelets from blood to inject a patient who has deficiency only in white cells.
4. Another common type of centrifuge called the cream separator is used to separate cream from whole milk.
5. Other centrifuges, the first being the Zippe-type, are used to separate isotopes, and these kinds of centrifuges are in use in nuclear power and nuclear weapon programs. Uranium-235, which is found in nature mixed with uranium-238, must be separated to be used to produce nuclear energy.

The separation can be done by a centrifuging process in which the uranium, contained in gas molecules, is rotated at high speed in a chamber so that the more massive molecules containing uranium-238 concentrate near the outer edge of the chamber and the lighter molecules containing uranium-235 concentrate near the axis. Several stages of centrifuging are needed to affect the required degree of separation.

6. Centrifuges are also used for such diverse purposes as simulating gravitational fields in space and for drying laundry.
7. Exceptionally large centrifuges are used to test the reactions of pilots and astronauts to acceleration above those experienced in the Earth's gravity.
8. In soil mechanics, centrifuges utilize centrifugal acceleration to match soil stresses in a scale model to those found in reality.
9. The ultracentrifuge is a centrifuge optimized for spinning a rotor at very high speeds, capable of generating acceleration as high as 1,000,000 G (9,800 km/s²). There are two kinds of ultracentrifuges, the preparative and the analytical ultracentrifuge. With the analytical ultracentrifuge, the sample being spun is observable through an optical detection system that allows the operator to observe the sample concentration in real time during the experiment. With modern instrumentation, these observations are electronically stored and computerized and can be analyzed after the fact. Two kinds of experiments are commonly performed on these instruments, sedimentation velocity experiments and sedimentation equilibrium experiments. The first are sensitive to both the shape and molar mass of the sample being studied, whereas the second are insensitive to the shape, but are sensitive to the molar mass of the sample being studied.

Application in Chemical Manufacturing Industry

Separation Process

In chemical manufacturing industry centrifuges are widely used to separate heavy substances from light using a phenomenon called centrifugation. Centrifugation involves the use of the centrifugal force for the separation of mixtures. In chemical manufacturing industry, a separation process is a process that transforms a mixture of substances into two or more compositionally-distinct products.[8]

Types of Separation Process

1. Sedimentation, flocculation, or centrifugation followed by decantation[3] - used when the mixture consists of substances of different densities. The less dense substances are poured off of the denser one. Flotation is a variation where suspended solids are encouraged to float to the top of the fluid by rising air bubbles.
2. Filtration - Mesh, bag and paper filters are used to remove large particulates suspended in fluids, e.g. fly ash, while membrane processes including microfilteration, ultrafiltration, reverse osmosis, dialysis utilizing synthetic membranes can separate micron-sized or smaller species. During the wine-making process, the removal by various means of undesirable matter suspended in the wine. Many wines undergo filtering a number of times before bottling, as finer and finer particles are cleared from the wine.[8]

3. Centrifugation - involves the use of the centrifugal force for the separation of mixtures. By increasing the effective gravitational force on a test tube so as to more rapidly and completely cause the precipitate to gather on the bottom on the tube. This process is used at large scale in various industries. The solution is then either quickly decanted from the tube without disturbing the precipitate or withdrawn by means of a medicine dropper.
4. Distillation - used for mixtures of liquids with different boiling points, or for a solid dissolved in a liquid. Distillation is the evaporation and subsequent collection of a liquid by condensation as a means of purification
5. Chromatography involves the separation of different dissolved substances as they travel through a material. The dissolved substances are separated based on their interaction with the stationary phase. Any of various techniques for the separation of complex mixtures that rely on the differential affinities of substances for a gas or liquid mobile medium and for a stationary adsorbing medium through which they pass, such as paper, gelatin, or magnesia.
6. Electrophoresis Organic molecules, such as protein are placed in a gel. A voltage is applied and the molecules move through the gel because they are charged. The gel restricts the motion so that different proteins will make different amounts of progress in any given time.
7. Extraction - liquid-liquid extraction is a useful method to separate components (compounds) of a mixture. The success of this method depends upon the difference in solubility of a compound in various solvents. Liquid-liquid extraction is based on the transfer of a solute substance from one liquid phase into another liquid phase according to the solubility.

Extraction becomes a very useful tool if you choose a suitable extraction solvent. You can use extraction to separate a substance selectively from a mixture, or to remove unwanted impurities from a solution.

8. Precipitation - Precipitation is the condensation of a solid from a solution during a chemical reaction. This occurs when the solution is supersaturated, whereupon the solid forms from the solute phase, and usually sinks to the bottom of the solution. This effect is useful in many industrial and scientific applications whereby a chemical reaction may produce a solid that can be collected from the solution by various methods (e.g. filtration, decanting, centrifuging). Precipitation from a solid solution is also a useful way to strengthen alloys.
9. Fractional freezing - Fractional freezing is a process used by chemists to separate two liquids which have a different freezing point. This happens by dropping the temperature of both liquids - one liquid will reach its freezing point and solidify, while the other will remain liquid. This liquid can be poured off, leaving the solid to warm and return to its liquid state. This process is used to increase the alcohol concentration in hard cider to make Applejack. It is also used in ice beer.[1]
10. Sieving - A sieve is a device for segregating aggregate based on particle size. Sieves commonly consist of a wire mesh on which the aggregate is placed. The sieve is then shaken, allowing particles smaller than the mesh openings to fall through. It may also be used in a garden to remove stones from soil.
11. Winnowing - Wind winnowing is a method developed by ancient cultures for agricultural purposes. It involves taking a basket of grain and chaff and tossing the contents into the air, thus causing the chaff to blow away while the heavier grains would fall back into the basket.

Basket Type Centrifuges at ABC Manufacturing Facility

ABC chemical manufacturing company has total eleven (11) centrifuges installed at its Herbicide/Fungicide manufacturing facility. These centrifuges were installed about 25-30 years ago. These machines are used to centrifuge or filtrate the dense product from slurry by dewatering or washing cycles.

Specifications:

Manufacturer: Ametek (process equipment division)

Type: Tolhurst 48" X 30" Quick-Dismantle Basket Type Centrifuge

Basket Diameter	48"	Basket RPM	1080
Basket Depth	30"	Centrifugal Force, G's	800
Filter Area Sq. Ft.	31.5	Bottom Discharge Dia	31.5"
Cake thickness (Approx)	7"	Feed pipe Size	2"
Capacity Cu. Ft.	16	Spray Nozzle Size	3/4"
Outlet Pipe Size	6"	Sight Glass Size	8"

Table 1 – Specifications of 'Ametek' Basket Type Horizontal Centrifuge

The rotating spindle is installed vertically in the centrifuge housing, allowing the basket to rotate on a vertical axis.

Main Features

- Center-Slung suspension – three point suspension on the case is in a plane near the center of gravity of the rotating basket. This reduces the effects of unbalanced loads and allows rotating mass to find its own center of gyration for smoother operation.

Pedestal suspension is provided with rubber pipe sleeve to avoid fatigue and breakage common to conventional spring loaded assemblies.

- Liquid and fume tight design.
- Raised 8 inch sight glass to visually check machine operation while running.
- Removable top cover for maintenance and inspections.
- Easy to install design of the non metallic filtrate media/cloth and metallic plow plate.
- Variable Hydraulic Drive offers maximum operating flexibility. This helps in choosing filter speed, to match product characteristics, as the basket speed is governed by the volume of oil delivered to the hydraulic motor.
- Dual Acting Unloader is operated hydraulically, moving the plow both vertically and laterally during slow speed unloading of the filtered product. Unloader controls are designed to prevent the plow from contacting the side wall of the basket during unloading. Solids are discharged through a bottom opening in the basket.
- Hydraulic motor housing is insulated to minimize operating noise.
- Cartridge type bearing assemblies can be removed intact from the machine for maintenance at a remote area. Reinstallation is equally quick and easy. Ball and roller bearing combination provide means of withstanding both radial and thrust loads.
- Quick release spindle is tapered for easy, frequent basket removal.
- Baskets are all welded construction, polished, statically and dynamically balanced for optimum performance. And longer bearing life.
- The design of feed cone which is located at the center of the basket accelerates the feed slurry and distributes it evenly around the periphery of the basket. This results in an even load of solids from top to bottom.

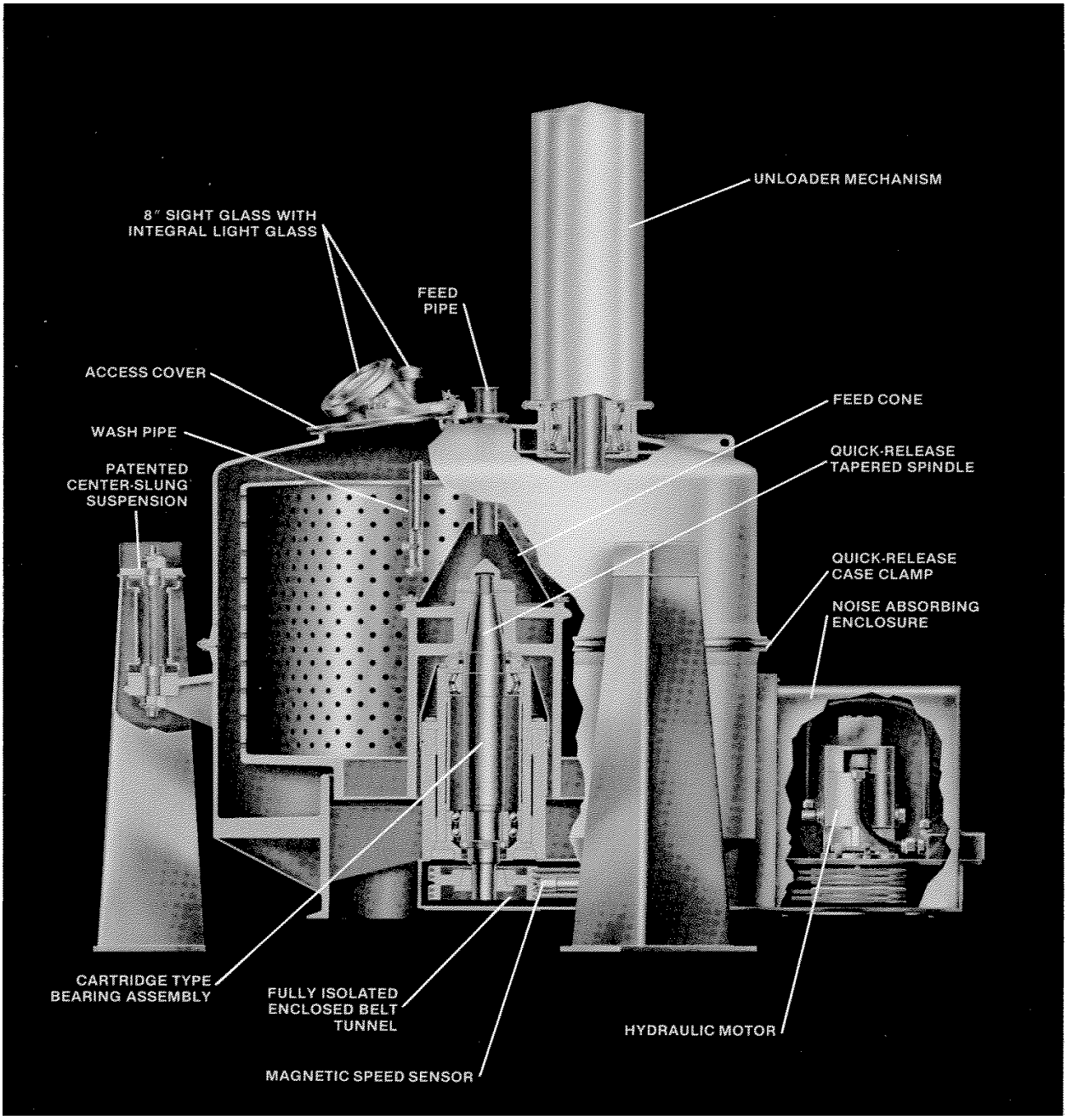


Figure 1 – Typical Basket type Ametek brand vertical Centrifuge Assembly[4]

Drawbacks and Problems

Actual unloading or plowing of the solids from the centrifuge basket is done at low speed. The unloader is powered hydraulically but its action is controlled electronically. The idle position of the unloader plow is in the raised position near the center of the position of the unloader during loading. This is the position of the unlaoder during loading, washing, and extracting the load. A safety feature is used to prevent the plow from moving it from its idle position in the event of loss of hydraulic power to the unloader during operation of the centrifuge. Limit switches and other cautionary measures are incorporated in the electrical control to make sure that centrifuge basket is rotating at the unloading speed before operating the unloader to remove the solids from the basket. Any attempt to remove the solids at a higher basket speed would result in severe damage and injury to the unloader, centrifuge and operator.

Even though these centrifuges have been around for years and ABC Company has been using them for longtime, there are lot of problems associated to these machines. Sometime these problems are hard to fix and need very experienced operators and mechanics all the time on the floor to trouble shoot.

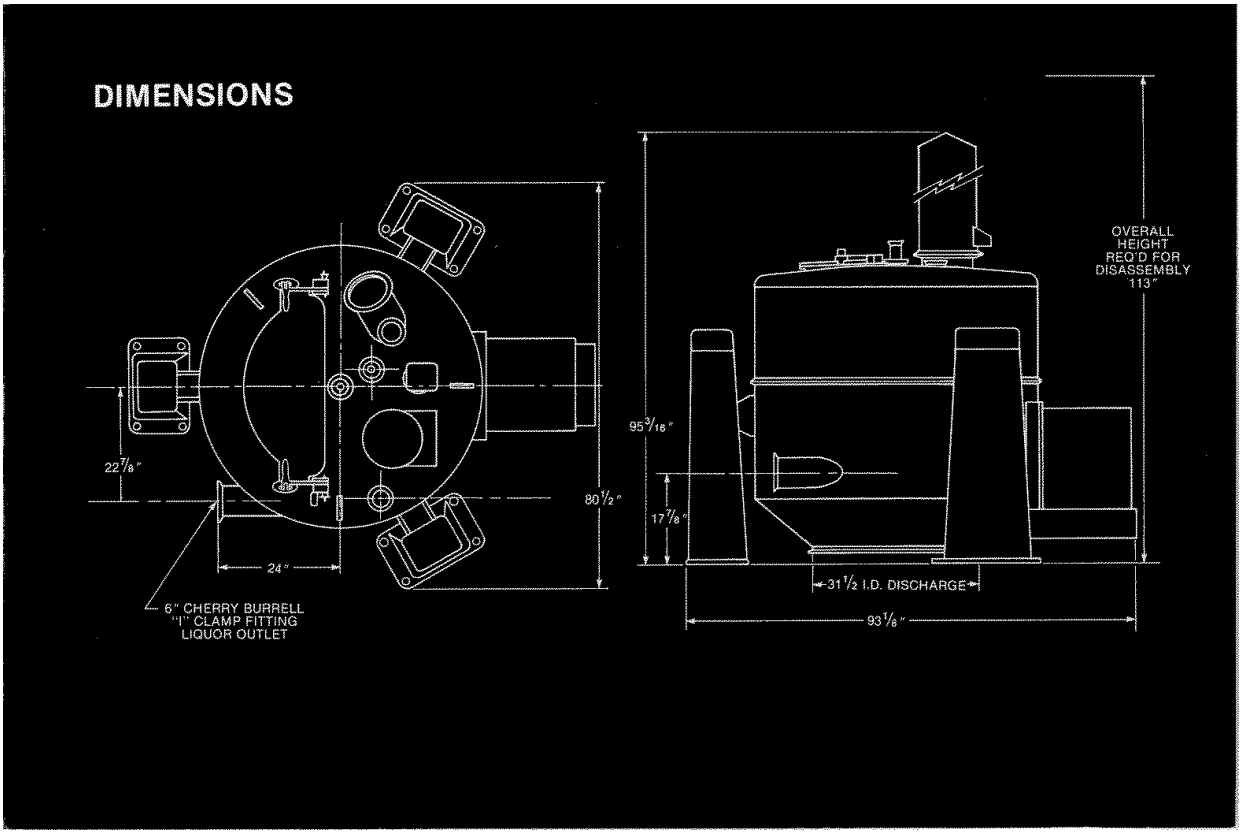


Figure 2 – Dimensional sketch of a typical Basket type Ametek brand vertical Centrifuge[4]

If any of the flow control valves in the hydraulic system are out of adjustment, the plow will rotate in to the basket too fast or too slow causing trouble in the whole cycle of centrifuge. Serious damage to machine occurs when plow moves too close to the basket which can happen if the clearance between the plow and basket is out of adjustment of was not set right from the get go. There are many hydraulically controlled components on these machines which make it very serious while operating at a very high speed. If control is lost for one reason or the other, the entire machine can go out of balance causing catastrophic damage to the machine. Once the centrifuge is out of balance, the plow will tear the cloth, plow screen or even basket. Basket turns in a vertical axis by the belt driven shaft/spindle. If the bearing is bad or belts are damaged the whole spindle can go out of balance which will ultimately cause damage to the filter cloth and

plow. The entire machine sits on suspension cables mounted on three pedestal legs. The suspension is always on continuously oscillating load and if because of wear and tear or high vibration, the suspension cable is damaged, the entire machine will shook apart.

These machines require high maintenance and have lot of reliability issues. When there is a breakdown, equipment down time is another serious problem which hinders production efficiency and makes production targets more difficult to achieve. Following are the main issues concerning these machines:

1. Old/aged equipment and technology which makes it hard to perform any modernization or modifications on the existing machines. These machines have already gone through all possible improvements in last thirty years.
2. High MTBF (mean time between failures) which means that these machines have a big reliability issue. Machine breakdown can occur for one or the other reason and it is hard to forecast the machine run until it fails.
3. High Maintenance Cost. Due to inherent design problems and age of the centrifuges, these machines require high maintenance budget to maintain. The maintenance cost involves:
    - Mechanical repairs cost
    - PCS repairs cost
    - Preventive Maintenance repairs cost
    - Turnaround Changeover cost
    - Oil analysis costs.
4. High operations cost. Dedicated operators are required to keep these centrifuges in good running parameters in the field. Lack of digital controls makes it hard to

monitor these machines from centralized control room. This adds headcounts in production crew which ultimately drives the product per pound cost high.

5. Spare parts issue is one of the most important. These machines are very old and 'original manufacturer' doesn't exist anymore and has gone through many buyouts and/or mergers. As the machines are obsolete so spare parts are not readily available from shelf. All spare parts have to be 'special made' which drives the cost high and also keeps ABC Company's spares inventory cost high.
6. Undesired production downtime is the biggest concern. Because of all of the above factors, it is very hard to keep these machines run in continuous operation without any undesired down time. When the centrifuge is not running, the centrifuging section of the plant will be shutdown and there will be no feed for the final step of the plant to feed which means a big production loss.

Below is photo of one of the Ametek basket type centrifuge installed at ABC's facility. It is evident from the photo that the condition of centrifuge and its components is very poor.

Figure 3 – Photo of an Ametek Centrifuge installed at ABC's plant

Historic Maintenance and Operational Cost

Maintenance spending on each centrifuge at ABC facility was collected from the achieved maintenance database MMIS and SAP (see appendix A). Data was carefully analyzed and was converted in to yearly spending numbers, taking in to account the inflation numbers *(data for years 2000, 2001, and 2002 was not possible to extract because of a glitch in ABC's system upgrade). The consolidated maintenance dollars are tabulated in table 2 below and a graphical representation is also made for comparison. Yearly average maintenance spending on these machines is calculated as $170,000.

Table 2 - 4.4/4.5 Centrifuges maintenance Cost history at ABC's Facility

Year	Maintenance Cost (in $)
2005	205,000
2004	200,000
2003	190,000
*1999	110,000
1998	220,000
1997	168,000
1996	200,000
1995	140,000
1994	150,000
1993	750,00
1992	200,000
Average maint. cost/Year	168,909

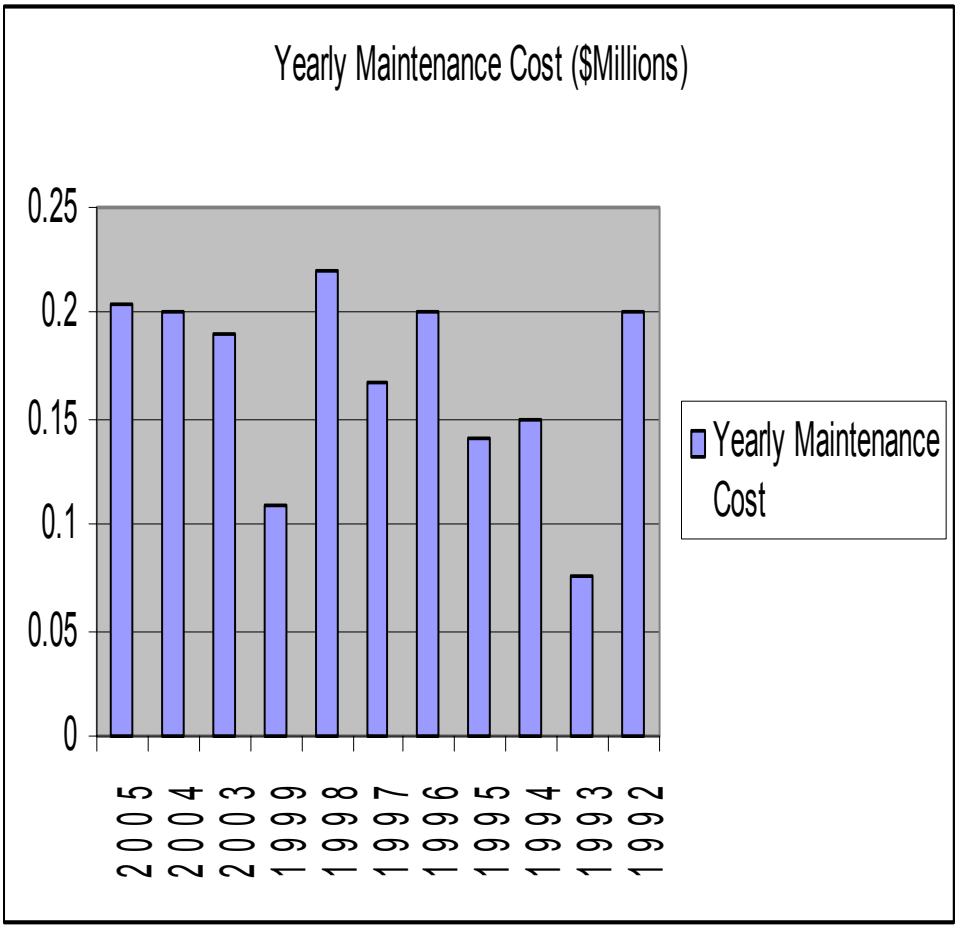


Table 3 – Graphical representation of centrifuges maintenance cost at ABC's facility

Yearly average maintenance spending on the centrifuges ~ $170,000

Estimated yearly operational Cost = $700,000 (considering two operators on the floor all the time while machines are operating during a campaign).

Total annual operating cost of existing centrifuges ~ $870,000

In addition to these two major costs, the biggest problem caused by these machines is the undesired production downtime. Loss of production time impacts big time on the yearly productions numbers.

Study of Alternatives and Replacement Theory

The decision among several competing investment alternatives must take in to account the fundamental purpose of a capital investment which is to obtain at least the minimum acceptable return from each dollar invested. Some times, in actual practice, there are usually a limited number of investment alternatives to consider and Centrifuge Replacement case falls in this category.

Basic principal on which the Alternative Selection Analysis of the centrifuge replacement project is done is described as "the alternative that requires the minimum investment of capital and produces satisfactory functional results is always chosen unless the incremental first cost associated with an alternative having a larger investment can be justified with respect to its incremental savings."[5]

Businesses must constantly decide whether existing assets should be continued in service or whether available new assets will better and more economically meet current and future needs. These decisions must be made with increasing frequency as the dynamic pace of business quickens and technology produces more rapid changes. Unfortunately, replacement projects sometimes are accompanied by unpleasant financial facts. Often it turns out that the earlier decisions, particularly concerning the anticipated useful life of existing assets, were not as good as might be desired, especially when hindsight can be applied. Consequently there is a tendency to regard the entire area of replacement as an emotional 'bugbear', whereas in fact it often represents economic opportunity.

Economic studies of replacement alternatives are performed in the same manner as economic studies of any other alternatives. The difference is that one alternative is to keep an existing old asset and there are one or more alternative replacement assets.

Replacement decisions are critically important to a firm. A hasty decision to get rid of equipment or faddishly to buy the most modern or elaborate equipment can be a serious drain on capital available. On the other hand a firm may go to the extreme by delaying replacement until it becomes noncompetitive or there is no other way to continue production.[5] Following are four main reasons for replacement of equipment:

Physical Impairment: The existing asset is worn out, owing to normal use or accident, and no longer will render its intended function unless repeated extensive repairs are made.

Inadequacy: The existing asset does not have sufficient capacity to fill the current and expected demands. Here clearly the requirements have changed from those that were anticipated at the time the time the asset was acquired. This condition does not necessarily imply physical impairment, but to meet the new demands the asset either must be supplemented or replaced.

Obsolescence: This may be of two types either functional or economic. Both types result in loss of profits. In case of functional obsolescence, there has been decrease in demand of the output thus a loss in revenue follows. Economic obsolescence is the result of there being a new asset that will produce at lower cost than can be obtained with the old asset.

Rental or lease possibilities: This is a variation of obsolescence, except that the replacement asset does not have to be different, in any aspect, from existing asset. The possible economic advantage is due to advantageous financial factors that sometimes may occur from leasing. These usually involve income tax considerations.

By analyzing the study of alternatives and replacement, it is obvious the old and aged centrifuges at ABC Company should be replaced with better design and high efficiency machines. In this case the reason for replacement is a combination of physical impairment, inadequacy, and

obsolescence. Peeler design centrifuges from following three manufacturers are considered for the alternative and replacement study on this project (these three manufacturers are selected after performing market study and getting feedbacks from few of the existing users in industry):

1. Krauss-Maffei Process Technology, Inc., Florence, KY
2. Bird Machine Co., South Walpole, MA
3. Flo Trend® Systems, Inc., Houston, TX

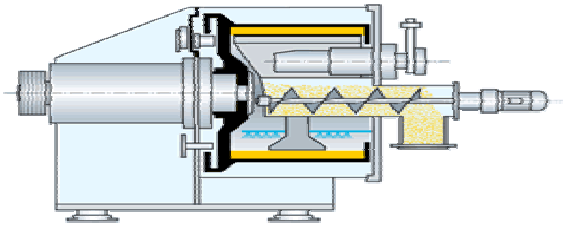


Figure 4: Pictorial view of a peeler type centrifuge from Krauss-Maffei Process Technology, Inc.

Figure 5 - Photo of a centrifuge from Bird Machine Co.

Figure 6 - Photo of a skid mounted centrifuge from Flo Trend® Systems, Inc.

Modern Era Peeler Type Centrifuges

In last three decades, since ABC Company installed its eleven centrifuges, a lot of progress has been made in centrifuge design and performance. These improvements were possible because of innovative ideas in the area of mechanics of materials, hydraulics, digital control systems, fluid flow and dynamics, thermodynamics, and operations management. The horizontal Peeler centrifuges are filtration centrifuges for batch wise operation for dehydration and washing of solid-liquid mixtures with fine and medium size particles of free flowing consistency.

Process Benefits of Peeler Centrifuges

In peeler type centrifuges the rotor is always in horizontal arrangement and cantilever mounted as opposed to a vertical rotor in Basket type machines. Peeler type centrifuge can handle difficult products of high viscosity, unfavorable spectrum, varying solids concentration and high degree of product purity. These machines can typically handle particle size from 0.01 mm, solid concentration from 20% weight, and throughputs feed from 0.01 cub meter per hour.[7]

These centrifuges can be designed to install in any hazardous location by utilizing explosion proof design, sturdy and gastight machine design and built in digital safety interlocks. Regeneration of residual heel, improved filtration capacity, intensive and efficient washing, and reduction of feed balance by evenly distributing the solids are some of the many benefits of peeler centrifuges.

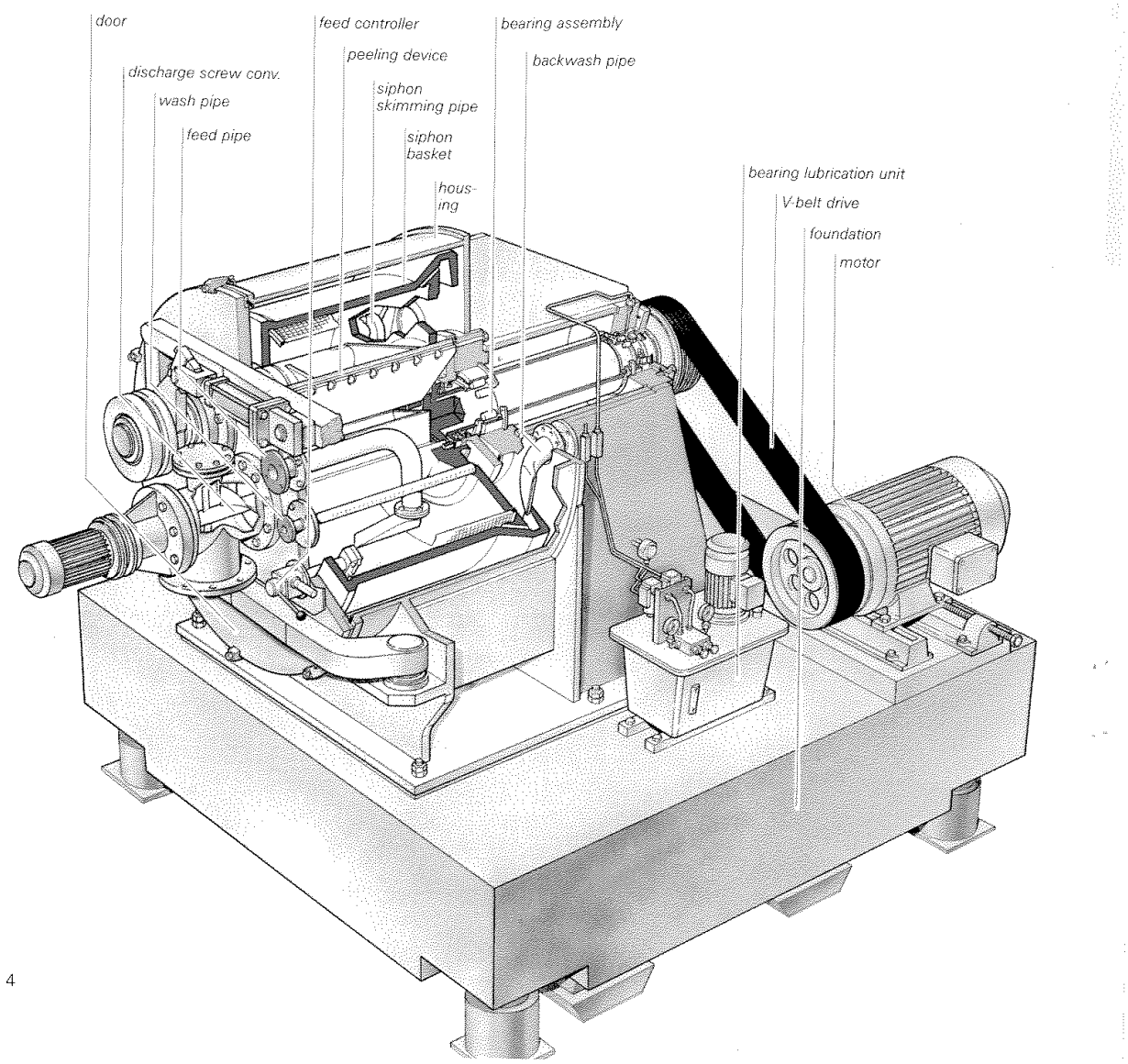
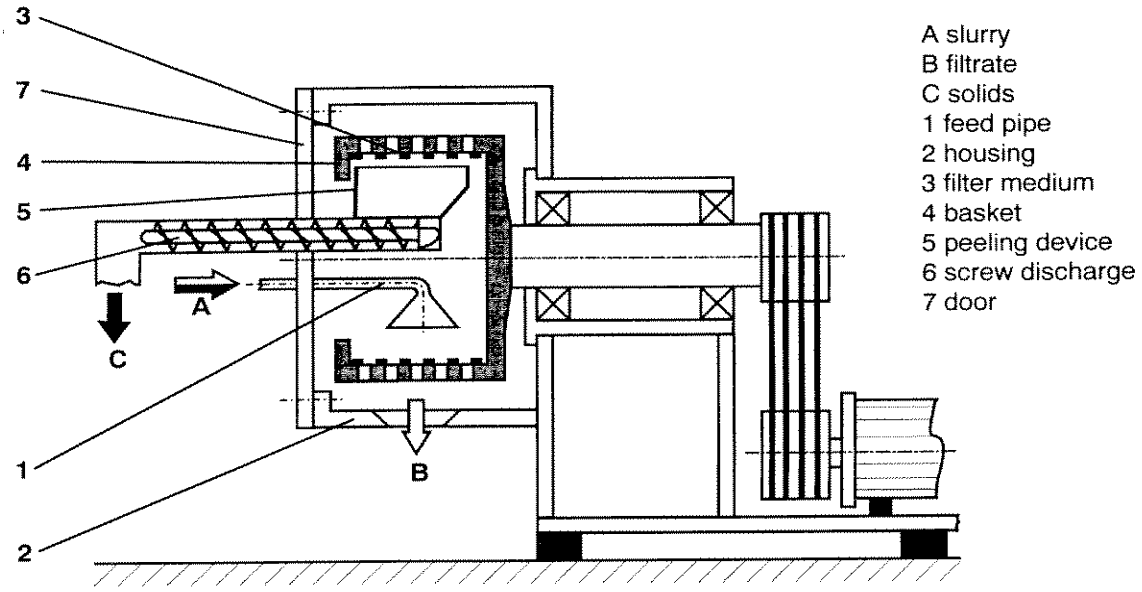


Figure 7 – Exploded view of a Peeler Type Centrifuge[3]

Mechanical design

The process area of a horizontal peeler centrifuge comprises essentially the cantilever mounted screen basket, the feed pipe with the feed distributor, the wash device, the peeling device, the solid outlet and the process housing. The drive unit consists essentially in the rotor drive and the rotor shaft with the bearings.



Process Area of a horizontal peeler centrifuge

The filter medium is installed inside of the cantilever mounted screen basket.

Figure 8 – Process Area of a Horizontal Peeler Centrifuge[3]

Processing

In horizontal peeler centrifuge the solid-liquid mixture to be separated is processed by the Distribution, Intermediate dewatering, Washing, Final dewatering, and Solid discharge operations. These operations are processed in the centrifuge successively and at the same place.[7] Figure below shows the processes operations.

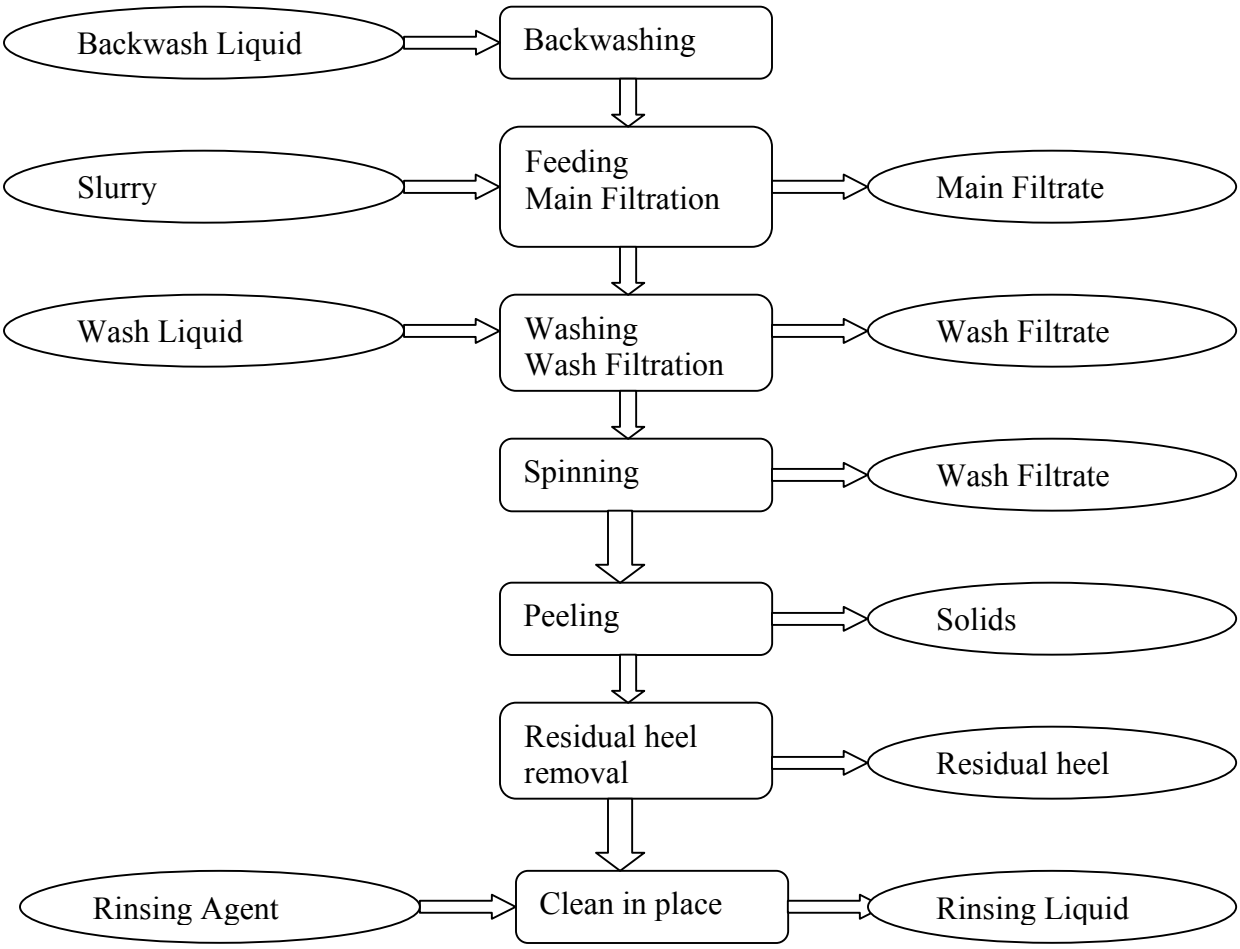


Figure 9 – Process Operations in a Horizontal Peeler Centrifuge[7]

Advantages of Peeler Centrifuges over Basket Centrifuges

These peeler centrifuges are normally provided with combination of digital and analog inputs and outputs including speed, peeler knife, siphon, vibration, and screw conveyor feed sensors. Better controls are installed and included inherently in design including bearing lubrication flow, lube tank flow, lube tank temperature, hydraulic tank level/flow, motor faults, and level sensors. All these controls help in running these centrifuges without much trouble. Trouble shooting is lot easier when there is a lot of data available to analyze. No major breakdown is anticipated because of robust design. Regular preventive maintenance keeps the centrifuge in good running condition. Better controls, better efficiency, less maintenance cost, less operation cost, and less floor space are the major advantages of peeler centrifuges over old basket type centrifuges.[3]

Investment Decision– Cost Comparison

Budget Development

The project budget, which is the final result of the planning cycle must be reasonable, attainable, and based of contractually negotiated costs and the statement of work. The basis for the budget is normally historical cost, best estimate, or industrial engineering standards. In ABC company case; the three potential manufacturers of centrifuges are selected for budget development by performing market study and getting feedbacks from few of the existing users in industry.[14] Following four categories of cost data are considered in the cost comparison exercise for centrifuge replacement project:

1. Design
2. Equipment
3. Labor
4. Material
5. Other direct charges
6. Overhead

Table 4 below provides the detail of estimated cost for purchase and installation of the new peeler design centrifuges at ABC facility. Improved specifications, better capacity, and the high efficiency of each peeler design centrifuge, existing eleven centrifuges at ABC company facility can be replaced with four* new centrifuges (see Appendix C for specs). These estimates are based on actual quotes from the vendors and historic installation and operational data at ABC facility on previous projects.

Description	Alternative A	Alternative B	Alternative C
Total Estimated Installed Cost for each (including Civil, Electrical, Structural, Instrumentation, Mechanical Equipment, Piping)	600,000	520,000	500,000
*Installed cost of four machines	2,400,000	2,220,000	2,200,000
Estimated useful life (years), based upon independent design reviews and feedback from actual users	25	18	14
Estimated yearly Operational labor cost	170,000	250,000	275,000
Estimated yearly Maintenance cost	20,000	35,000	35,000
Estimated total annual operational cost	190,000	285,000	310,000

Where:
Alternative A is 'Krauss Maffei'
Alternative B is 'Bird Machine'
Alternative C is 'Flo Trend'

Table 4 – Estimated installed and operational cost comparison of three proposed alternatives

Economic Selection Criteria and Capital Budgeting

As a rule of project management, it is highly unlikely that any organization will approve a project where the costs exceed the benefits. Benefits can be measured in financial or non-financial terms. Capital budgeting is defined as the decision making process by which organizations evaluate projects that include major fixed assets such as machinery, buildings, and equipment.[15] There are various capital budgeting techniques available, and following are used to get estimated numbers in case of centrifuges replacement project:

Payback Period: The payback period is the exact length of time needed for a firm to recover its initial investment. Payback period is the least of prices of all capital budgeting methods because the calculations are in dollars and not adjusted for the time value of money. Table below

provides total yearly savings and investment payback period for all three alternatives. Payback period for all three are very close, Alternative A having highest payback period of 1.05 years.

Alternative	Yearly Savings in Operational Cost	Yearly Savings by increased production	Total yearly saving	Investment Payback (years)
Alternative A	680,000	1,600,000	2,280,000	1.05
Alternative B	585,000	1,600,000	2,185,000	1.02
Alternative C	560,000	1,600,000	2,160,000	1.02

*Based upon the assumption that Company ABC makes 800 more pounds of product every year because of decrease in undesired production down time and each pound is sold for $2,000.

Net Present Value: The difference between an investment's market value and its cost is called Net Present Value of the investment, abbreviated NPV. NPV is a sophisticated capital budgeting techniques that equates the discounted cash flows against the initial investment.[15]

$NPV = {}_{t=1}\sum^{n} [FV_t / (1+K)^t] - II$; Where: FV = Future Value = $PV(1+k)^n$, k = Interest Rate or cost of capital, n = Number of years, II = Initial Investment

NPV can also be calculated by using Microsoft Excel spreadsheet financials function

Initial Investment	Expected cash flow (savings)			
	Year 0	Year 1	Year 2	
2,400,000	-2,400,000	-120,000	2,160,000	Alternative A
2,220,000	-2,220,000	-35000	2,150,000	Alternative B
2,200,000	-2,200,000	-40,000	2,120,000	Alternative C

Assuming discount rate of 10%, below is the calculation for NPV values for each alternative.

	Alternative A	Alternative B	Alternative C
NPV	$723,966.94	-$474,958.67	$484,297.52

If total savings are available till the payback period for each alternative, NPV values can be easily calculated. If the NPV is greater than or equal to zero dollars, investment should be made whereas if NPV is less than zero dollars, project should be rejected. From this criterion Alternative A is the best investment option.

Internal Rate of Return: Internal Rate of Return (IRR) is probably the most sophisticated budgeting technique. IRR is the discount rate where the present value of the cash inflows exactly equals the initial investment.[14] In other worlds, IRR is the discount rate when NPV = 0

	Alternative A	Alternative B	Alternative C
IRR	8%	2%	3%

Using IRR financial function in Excel spreadsheet, 'Alternative A' investment option is the best and should be chosen.

Summary

Because of improved specifications, better capacity, and the high efficiency of peeler design centrifuge, existing eleven basket type centrifuges at ABC facility should be replaced with four new peeler centrifuges (see Appendix C for comparing specs). Annual saving numbers, NPV, IRR, and expected useful life calculations confirm that Kraus Mafei Peeler centrifuge, Alternative A, should be the best choice out of suggested three alternatives machines.

Results and Conclusion

Because of improved specifications, better capacity, and the high efficiency of peeler design centrifuge, existing eleven basket type centrifuges at ABC facility should be replaced with four new peeler centrifuges (see Appendix C for comparing specs). Annual saving numbers, NPV, IRR, and expected useful life facts in previous pages confirm that Kraus Mafei Peeler centrifuge, Alternative A, is the be choice out of suggested three alternatives machines. Following are the vital proven advantages of peeler centrifuges by this study proposal, which should be included in the final justification of the project:

1. Significant operational cost savings
2. High equipment reliability
3. Significant savings achieved by attaining smooth continuous plant operation without experiencing undesired breakdowns and thus no production loss
4. Enhanced personal safety and reduced product exposure
5. Flexibility of running at higher rates in case of increased future demands
6. Significant savings in maintenance cost
7. Readily availability of spare parts from manufacturer
8. Better utilization of 'DCS' digital control systems trained workforce
9. Savings in plant turnaround times and cost because of less maintenance involved
10. Ease in adaptability of equipment to any new product manufacturing process when idle (approximately four months in a calendar year), thus a better chance of future increased asset utilization efficiency.

Suggestions for Additional Work

This study has been conducted by taking in to consideration the major cost factors involved in capital investment decision making. Few assumptions were made while performing NPV/IRR calculations and especially estimating the average yearly dollar value of production loss caused due to undesired failure of the existing machines. Estimated power consumption comparison between the existing and proposed machined is not performed as a part of study. To find a comprehensive justification of the capital investment, further additional work is required to document these factors and their impact on the expected savings. It is very important that expected return on investment (ROI) and pay off time are very accurately calculated, by considering all applicable scenarios, before making this investment. It is recommended that the life cycle and future long-term (15-20 years) forecast/demand of the product being made at ABC's facility, by utilizing these machines, is thoroughly studied to justify the spending. A comprehensive modification request draft should be prepared and discussed within various functional teams and a factual justification statement should be prepared before seeking the capital money for investment. It is recommended that an option of implementing the project in phases is considered which will allow one machine installation at a time and will provide actual data to analyze the expected improved performance before installing rest of the machines. Last but not least any process modification or alternative to the whole centrifuging process should be investigated before making final plans of spending capital money for peeler centrifuges.

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Appendix A

Work order maintenance cost history summary (1992-2005) for eleven centrifuges installed at 'ABC' manufacturing facility, extracted from archived files.

Appendix B

Photos of the basket type vertical Ametek centrifuges installed at ‘ABC’ Manufacturing facility showing their deteriorated condition.

Appendix C

Engineering specification for Horizontal Peeler Centrifuge, prepared by ABC Manufacturing.

Appendix D

Requirements for Centrifuge design drawings, prepared by ‘ABC’ Manufacturing.

Appendix E

ABC Manufacturing ‘Equipment Bid Tabulation’.

Appendix F

Manufacturer's data requirements for Mechanical and Electrical Equipment, by ABC manufacturing.